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PTO/SB/05 (12/97)
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UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 CFR 1.53(b)

Attorney Docket No. 005158.P003 Total Pages 3

First Named Inventor or Application Identifier Hui Liu

Express Mail Label No. EL143569137US

jc860 U.S. PTO
09/692681
10/18/00

ADDRESS TO: **Assistant Commissioner for Patents**
Box Patent Application
Washington, D. C. 20231

APPLICATION ELEMENTS
See MPEP chapter 600 concerning utility patent application contents.

1. X Fee Transmittal Form
(Submit an original, and a duplicate for fee processing)

2. X Specification (Total Pages 37)
(preferred arrangement set forth below)
- Descriptive Title of the Invention
- Cross References to Related Applications
- Statement Regarding Fed sponsored R & D
- Reference to Microfiche Appendix
- Background of the Invention
- Brief Summary of the Invention
- Brief Description of the Drawings (if filed)
- Detailed Description
- Claims
- Abstract of the Disclosure

3. X Drawings(s) (35 USC 113) (Total Sheets 6)

4. X Oath or Declaration (Total Pages 5)

a. ___ Newly Executed (Original or Copy)

b. ___ Copy from a Prior Application (37 CFR 1.63(d))
(for Continuation/Divisional with Box 17 completed) **(Note Box 5 below)**

i. ___ DELETIONS OF INVENTOR(S) Signed statement attached deleting inventor(s) named in the prior application, see 37 CFR 1.63(d)(2) and 1.33(b).

5. _ Incorporation By Reference (useable if Box 4b is checked)
The entire disclosure of the prior application, from which a copy of the oath or declaration is supplied under Box 4b, is considered as being part of the disclosure of the accompanying application and is hereby incorporated by reference therein.

6. _ Microfiche Computer Program (Appendix)

7. __ Nucleotide and/or Amino Acid Sequence Submission
(if applicable, all necessary)
a. ____ Computer Readable Copy
b. ____ Paper Copy (identical to computer copy)
c. ____ Statement verifying identity of above copies

ACCOMPANYING APPLICATION PARTS

8. __ Assignment Papers (cover sheet & documents(s))
9. __ a. 37 CFR 3.73(b) Statement (where there is an assignee)
__ b. Power of Attorney
10. __ English Translation Document (if applicable)
11. __ a. Information Disclosure Statement (IDS)/PTO-1449
__ b. Copies of IDS Citations
12. __ Preliminary Amendment
13. X___ Return Receipt Postcard (MPEP 503) (Should be specifically itemized)
14. __ a. Small Entity Statement(s)
b. Statement filed in prior application, Status still proper and desired
15. __ Certified Copy of Priority Document(s) (if foreign priority is claimed)
16. __ Other: _____

17. **If a CONTINUING APPLICATION,** check appropriate box and supply the requisite information:
___ Continuation ____ Divisional ____ Continuation-in-part (CIP)
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18. **Correspondence Address**
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or
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FEE TRANSMITTAL FOR FY 2001

TOTAL AMOUNT OF PAYMENT ($) 1,076.00

Complete if Known:
Application No. Not Yet Assigned
Filing Date October 18, 2000
First Named Inventor Hui Liu
Group Art Unit Not Yet Assigned
Examiner Name Not Yet Assigned
Attorney Docket No. 005158.P003

METHOD OF PAYMENT (check one)

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FEE CALCULATION

1. BASIC FILING FEE

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
101	710	201	355	Utility application filing fee	710.00
106	320	206	160	Design application filing fee	0
107	490	207	245	Plant filing fee	0
108	710	208	355	Reissue filing fee	0
114	150	214	75	Provisional application filing fee	0

SUBTOTAL (1) $ 710.00

2. EXTRA CLAIM FEES

		Extra Claims		Fee from below		Fee Paid
Total Claims	27	– 20** =	7	X 18.00	=	126.00
Independent Claims	6	– 3** =	3	X 80.00	=	240.00
Multiple Dependent					=	0

**Or number previously paid, if greater; For Reissues, see below.

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description
103	18	203	9	Claims in excess of 20
102	80	202	40	Independent claims in excess of 3
104	270	204	135	Multiple dependent claim, if not paid
109	80	209	40	**Reissue independent claims over original patent
110	18	210	9	**Reissue claims in excess of 20 and over original patent

SUBTOTAL (2) $ 366.00

FEE CALCULATION (continued)

3. ADDITIONAL FEES

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
105	130	205	65	Surcharge - late filing fee or oath	
127	50	227	25	Surcharge - late provisional filing fee or cover sheet	
139	130	139	130	Non-English specification	
147	2,520	147	2,520	For filing a request for reexamination	
112	920*	112	920*	Requesting publication of SIR prior to Examiner action	
113	1,840*	113	1,840*	Requesting publication of SIR after Examiner action	
115	110	215	55	Extension for response within first month	
116	390	216	195	Extension for response within second month	
117	890	217	445	Extension for response within third month	
118	1,390	218	695	Extension for response within fourth month	
128	1,890	228	945	Extension for response within fifth month	
119	310	219	155	Notice of Appeal	
120	310	220	155	Filing a brief in support of an appeal	
121	270	221	135	Request for oral hearing	
138	1,510	138	1,510	Petition to institute a public use proceeding	
140	110	240	55	Petition to revive unavoidably abandoned application	
141	1,240	241	620	Petition to revive unintentionally abandoned application	
142	1,240	242	620	Utility issue fee (or reissue)	
143	440	243	220	Design issue fee	
144	600	244	300	Plant issue fee	
122	130	122	130	Petitions to the Commissioner	
123	50	123	50	Petitions related to provisional applications	
126	240	126	240	Submission of Information Disclosure Stmt	
581	40	581	40	Recording each patent assignment per property (times number of properties)	
146	710	246	355	For filing a submission after final rejection (see 37 CFR 1.129(a))	
149	710	249	355	For each additional invention to be examined (see 37 CFR 1.129(b))	
179	710	279	355	Request for Continued Examination (RCE)	
169	900	169	900	Request for expedited examination of a design application	

Other fee (specify) _____

Other fee (specify) _____

SUBTOTAL (3) $ 0

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SUBMITTED BY:

Typed or Printed Name: Michael J. Mallie

Signature: _____ Date: 10/18/00

Reg. Number: 36,591 Telephone Number: _____

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Serial/Patent No.: *** Filing/Issue Date: ***
Client: Broadstorm Communications
Title: CHANNEL ALLOCATION IN BROADBAND ORTHOGONAL FREQUENCY-DIVISION MULTIPLE-ACCESS/SPACE-DIVISION MULTIPLE-ACCESS...
BSTZ File No.: 005158.P003 Atty/Secty Initials: MJM/amq
Date Mailed: 10/18/00 Docket Due Date: ***

The following has been received in the U.S. Patent & Trademark Office on the date stamped hereon:

- ☐ Amendment/Response (____ pgs.)
- ☐ Appeal Brief (____ pgs) (in triplicate)
- ☒ Application - Utility (37 pgs., with cover and abstract)
- ☐ Application - Rule 1.53(b) Continuation (____ pgs)
- ☐ Application - Rule 1.53(b) Divisional (____ pgs.)
- ☐ Application - Rule 1.53(b) CIP (____ pgs)
- ☐ Application - Rule 1.53(d) CPA Transmittal (____ pgs)
- ☐ Application - Design (____ pgs.)
- ☐ Application - PCT (____ pgs)
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- ☐ Assignment and Cover Sheet
- ☒ Certificate of Mailing
- ☒ Declaration & POA (5 pgs.) (unsigned)
- ☐ Disclosure Docs & Orig & Copy of Inventor's Signed Letter(____pgs)
- ☒ Drawings: 6 # of sheets includes 6 figures

- ☒ Express Mail No: EL143569137US
- ☐ ____ Month(s) Extension of Time
- ☐ Information Disclosure Statement & PTO-1449 (__ pgs)
- ☐ Issue Fee Transmittal
- ☐ Notice of Appeal
- ☐ Petition for Extension of Time
- ☐ Petition for ____
- ☒ Postcard
- ☐ Power of Attorney (____ pgs)
- ☐ Preliminary Amendment (____ pgs)
- ☐ Reply Brief (____ pgs)
- ☐ Response to Notice of Missing Parts
- ☐ Small Entity Declaration for Indep. Inventor/Small Business
- ☒ Transmittal Letter, ~~in duplicate~~ XXXXXX
- ☒ Fee Transmittal, in duplicate

- ☐ Check No 38398 Amt. 1,076.
- ☐ Check No ____ Amt ____

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UNITED STATES PATENT APPLICATION

for

CHANNEL ALLOCATION IN BROADBAND ORTHOGONAL FREQUENCY-DIVISION MULTIPLE-ACCESS/SPACE-DIVISION MULTIPLE-ACCESS NETWORKS

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10-18-00

(Date signed)

CHANNEL ALLOCATION IN BROADBAND ORTHOGONAL FREQUENCY-DIVISION MULTIPLE-ACCESS/SPACE-DIVISION MULTIPLE-ACCESS NETWORKS

FIELD OF THE INVENTION

The present invention relates to the field of communications systems; more particularly, the present invention relates to orthogonal frequency-division multiple-access (OFDMA) networks that employ space-division multiple-access.

BACKGROUND OF THE INVENTION

For broadband wireless networks that support mixed traffic, it is required that a medium access control (MAC) be able to effectively adapt to changing channel conditions and traffic requirements. One of the key resources in wireless communication is the spatial diversity provided by antenna arrays. Efficient exploitation of spatial diversity is fundamentally important to resource critical wireless applications. See Tsoulos, "Smart Antennas For Mobile Communication Systems: Benefits and Challenges," Electronics and Communication Engineering Journal, Vol. 11(2), April 1999.

One of the most aggressive ways of exploiting the spatial diversity is space-division multiple-access (SDMA), or spatial multiplexing, that attempts to multiply the throughput of a wireless network by introducing

"spatial channels". The benefits of SDMA in narrowband applications have be investigated by Shad et al., "Indoor SDMA Capacity Using a Smart Antenna Base Station," IEEE Proc. ICUPC'97, pp. 868--872, 1997; Farsakh et al., "On the Mobile Radio Capacity Increase Through SDMA," Accessing, Transmission, Networking Proceedings, pp. 293-297, 1998; Xu et al., "Throughput Multiplication of Wireless LANs for Multimedia Services: SDMA Protocol Design," Proc. Globecom'94, San Francisco, CA, November 1994; Ward et al., "High Throughput Slotted ALOHA Packet Radio Networks with Adaptive Arrays," IEEE Trans. COM, Vol. 41(3), pp. 460-470, March 1993. The narrowband SDMA scheme is particularly suitable for fixed wireless networks where the spatial characteristics are relatively stable. For a system with M antenna elements, the underlying idea is to allow M subscribers to share a time-division multiple-access (TDMA) slot through M spatial channels/slots, so that the total number of non-interfering traffic channels can be increased by M fold.

Though intuitively promising, an obvious flaw of this scheme is that spatial channels are rarely orthogonal in practice. In other words, traffic over SDMA channels are mutually interfering. If multiple subscribers are assigned to one time slot without considering these spatial characteristics,

the one with an unfavorable spatial configuration may experience significant throughput disadvantages. Since the effectiveness of spatial separation depends on the base-station array responses (often referred to as the spatial signatures) of all co-slot subscribers and the spatial processing technique employed, the instantaneous signal-to-noise-plus-interference ratio (SINR) of spatially multiplexed outputs can vary dramatically. This problem is investigated by Ward et al., "High Throughput Slotted ALOHA Packet Radio Networks with Adaptive Arrays," IEEE Trans. COM, Vol. 41(3), pp 460-470, March 1993, where collision due to un-resolvable packets (when the arrival angles of multiple packets are within a threshold) is accounted for. Although the analysis is somewhat simplified, the study reveals some of the key limitations of basic SDMA scheme.

A fundamental solution to the above problem is the "channel-aware" MAC protocol that assigns traffic channels based on the spatial characteristics of the subscribers. Using such a protocol, the performance of SDMA system can be enhanced with spatial signature-based scheduling (e.g., assigning the "less-interfering" subscribers to the same time slot to increase the traffic throughput). The MAC treatment allows a system to exploit the spatial diversity in an efficient manner using spatial processing

with fixed-complexity. Several scheduling algorithms are proposed and studied for "narrow band" systems where the spatial characteristics can be described by a one-dimensional vector; see Shad et al., "Indoor SDMA Capacity Using a Smart Antenna Base Station," IEEE Proc. ICUPC'97, pp. 868-872, 1997; Farsakh et al., "On the Mobile Radio Capacity Increase through SDMA," Accessing, Transmission, Networking Proceedings, pp. 293-297, 1998; and U.S. Patent No. 6,041,237, "Method of Channel Allocation," issued March 21, 2000.

All of the existing channel allocation schemes, however, consider "narrowband" TDMA wireless network in conjunction with SDMA. None of them is applicable to broadband wireless networks. The prime reason is that in broadband application, subscribers' spatial channels are two-dimensional, in both space and frequency, and channel assignment under spatial multiplexing becomes a more involved problem.

Recently, there is an increasing interest in frequency division multiple access (OFDMA) based broadband wireless networks. OFDMA can be viewed from one perspective as attempting to achieve system capacity over multiple-subscriber broadband wireless channels.

SUMMARY OF THE INVENTION

A network is described. In one embodiment, the network comprises multiple subscriber units to communicate with the base station using an orthogonal frequency-division multiple-access (OFDMA) protocol, and a base station. The base-station includes a memory unit to store broadband spatial signature vectors associated with each subscriber and traffic channel allocation logic. The vectors are a function of frequency. The traffic channel allocation logic allocates OFDMA channels using the broadband spatial signature vectors of the subscribers.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be understood more fully from the detailed description given below and from the accompanying drawings of various embodiments of the invention, which, however, should not be taken to limit the invention to the specific embodiments, but are for explanation and understanding only.

Figure 1A illustrates multiple subscribers.

Figure 1B illustrates randomly assigning subscribers to channels and the idea of "spatial signature-aware" channel assignment, where less interfering subscribers are assigned to the same traffic slot to increase system capacity.

Figure 2 shows accommodating a high data rate with parallel narrowband data streams transmitted over OFDMA traffic channels.

Figure 3 illustrates channel assignment in OFDMA/SDMA in the presence of on-going traffics.

Figure 4 shows the achievable rates of accessing subscribers in each of the OFDMA traffic channels in the presence of on-going subscribers.

Figure 5 is a block diagram of one embodiment of an OFDMA/SDMA base-station.

Figure 6 is a decision making flow of one embodiment of the OFDMA/SDMA traffic channel allocation logic.

DETAILED DESCRIPTION OF THE PRESENT INVENTION

A network described herein combines orthogonal frequency-division multiple-access (OFDMA) with space-division multiple-access (SDMA) to provide an OFDMA/SDMA protocol that offers an increase in capacity, while assigning OFDMA/SDMA traffic channels to multiple-access subscribers based on their broadband (two-dimensional) channel characteristics. In one embodiment, such a network is a cellular network implementing OFDMA in conjunction with spatial multiplexing in a broadband wireless cellular network. The cellular network includes a base-station with spatially separated transceivers and multiple subscribers communicating with the base-station using an OFDMA protocol. The term "subscriber" or "subscribers" is used herein to refer to a subscriber unit or device.

The network includes traffic channel allocation logic that increases, and potentially maximizes, the network throughput based on the broadband propagation characteristics between the base-station and the subscribers. In one embodiment, each traffic channel is a cluster of OFDM sub-carriers that may be shared by multiple subscribers through spatial multiplexing. When a new link between the base-station and a subscriber is to be established, the

traffic channel allocation logic first estimates two-dimensional (space and frequency/time) broadband propagation channels between the base-station and the new subscriber. Frequency and time are the same time represented in two different domains. The traffic channel allocation logic then accommodates a rate request received from the new subscriber by assigning traffic channels that utilizes a predetermined (e.g., the minimum) amount of transmission power (in comparison to the amount of transmission power necessary to transmit over one or more other OFDMA traffic channels that were not assigned to the new subscriber) and causes a certain amount of interference (e.g., the least interference in comparison to the interference to other subscribers caused by the new subscriber using one or more of the OFDMA traffic channels that were not assigned to the new subscriber) to co-channel subscribers. The rate request is received from the subscriber either prior to the process of establishing the new link or concurrently therewith.

In alternative embodiments, the traffic channel allocator logic assigns traffic channels that require use of an amount of transmission power greater than the minimum and/or cause an amount of interference greater than those channels that cause the least interference (if used for the new subscriber's traffic). Such assignments may, for example, be used on other

channel allocation or loading requests by made at the same time or scheduled to occur in the future.

In the following description, numerous details are set forth in order to provide a thorough understanding of the present invention. It will be apparent, however, to one skilled in the art, that the present invention may be practiced without these specific details. In other instances, well-known structures and devices are shown in block diagram form, rather than in detail, in order to avoid obscuring the present invention.

Some portions of the detailed descriptions which follow are presented in terms of algorithms and symbolic representations of operations on data bits within a computer memory. These algorithmic descriptions and representations are the means used by those skilled in the data processing arts to most effectively convey the substance of their work to others skilled in the art. An algorithm is here, and generally, conceived to be a self-consistent sequence of steps leading to a desired result. The steps are those requiring physical manipulations of physical quantities. Usually, though not necessarily, these quantities take the form of electrical or magnetic signals capable of being stored, transferred, combined, compared, and otherwise manipulated. It has proven convenient at times, principally for

reasons of common usage, to refer to these signals as bits, values, elements, symbols, characters, terms, numbers, or the like.

It should be borne in mind, however, that all of these and similar terms are to be associated with the appropriate physical quantities and are merely convenient labels applied to these quantities. Unless specifically stated otherwise as apparent from the following discussion, it is appreciated that throughout the description, discussions utilizing terms such as "processing" or "computing" or "calculating" or "determining" or "displaying" or the like, refer to the action and processes of a computer system, or similar electronic computing device, that manipulates and transforms data represented as physical (electronic) quantities within the computer system's registers and memories into other data similarly represented as physical quantities within the computer system memories or registers or other such information storage, transmission or display devices.

The present invention also relates to apparatus for performing the operations herein. This apparatus may be specially constructed for the required purposes, or it may comprise a general purpose computer selectively activated or reconfigured by a computer program stored in the computer. Such a computer program may be stored in a computer readable

storage medium, such as, but is not limited to, any type of disk including floppy disks, optical disks, CD-ROMs, and magnetic-optical disks, read-only memories (ROMs), random access memories (RAMs), EPROMs, EEPROMs, magnetic or optical cards, or any type of media suitable for storing electronic instructions, and each coupled to a computer system bus.

The algorithms and displays presented herein are not inherently related to any particular computer or other apparatus. Various general purpose systems may be used with programs in accordance with the teachings herein, or it may prove convenient to construct more specialized apparatus to perform the required method steps. The required structure for a variety of these systems will appear from the description below. In addition, the present invention is not described with reference to any particular programming language. It will be appreciated that a variety of programming languages may be used to implement the teachings of the invention as described herein.

A machine-readable medium includes any mechanism for storing or transmitting information in a form readable by a machine (e.g., a computer). For example, a machine-readable medium includes read only memory ("ROM"); random access memory ("RAM"); magnetic disk storage media;

optical storage media; flash memory devices; electrical, optical, acoustical or other form of propagated signals (e.g., carrier waves, infrared signals, digital signals, etc.); etc.

Overview

Efficient exploitation of spatial diversity in high-speed wireless network is a challenging task due to the broadband nature of spatial channel characteristics. In OFDMA networks, the wide spectrum is partitioned into parallel narrowband traffic channels. The methodology described herein increases, and potentially maximizes, the capacity of a broadband OFDMA/SDMA network through intelligent traffic channel assignment.

The concept of channel assignment for narrowband SDMA networks is illustrated in Figure 1. In such application, each spatial channel can be described by a vector, referred to herein as a narrowband "spatial signature." For a system with M antenna elements, the spatial signature can be represented as A_i a_i, where A_i is a fading coefficient of the channel and a_i=[a_1i, a_2i, …, a_Mi] is an Mx1 vector that characterizes the relative complex gains between antennas. The level of interference between co-channel subscribers (sharing the same spectral resource, e.g., the same time

slot/the same frequency/the same code (e.g., the spreading code) is determined by the degree of orthogonality between their corresponding spatial signatures. (See Farsakh et al., "On the Mobile Radio Capacity Increase Through SDMA", Accessing, Transmission, Networking Proceedings, pp. 293-297, 1998.) Referring to the example in Figure 1A, the spatial signatures of subscribers 1, 3, and 5 are almost orthogonal, so are those of subscribers 2 and 4. On the other hand, the spatial signatures of subscribers 1 and 2 are near aligned, indicating strong mutual interference should they be assigned to the same traffic channel.

Conventional SDMA simply assigns subscribers to their traffic channels (time slots in this case) in a pre-determined order. For example, in top of Figure 1B, subscriber 1 and 2 are allocated to the same time slots, while being separated in space. Similarly, subscribers 3 and 4 are allocated to the same time slot while being separated in space. The possibility of strong interference between co-channel subscribers (in this particular example: slot 1, between subscribers 1 and 2; slot 2, between subscribers 3 and 4) is high. To reduce the interference level and improve the system capacity, traffic channels are assigned in a way that the most (if not all) interfering subscribers are allocated to different time slots (as in bottom of

Figure 1B). By lifting the worst case performance, significant capacity gains can be achieved using this strategy without undue complexity in spatial processing.

The channel assignment problem becomes much more involved in broadband applications (e.g., broadband antenna array systems, etc.) where the spatial signature is no longer a vector. In the case of the OFDMA-based network described herein, high data rate traffic is accommodated with multiple low-rate (narrowband) data streams over orthogonal narrowband traffic channels. These narrowband traffic channels, centered at different frequencies, provide a parallel structure for higher flexibility and ease of implementation. Figure 2 illustrates such a structure in which high data rate traffic 201 is provided in the form of parallel data streams over orthogonal narrowband traffic channels centered at different frequencies. As a result, the "broadband spatial signature" associated with each subscriber becomes a two-dimensional matrix, or a set of narrowband spatial signature vectors that are a function of the frequency. In one embodiment, the spatial signature of subscriber i in OFDMA is given by

$$[A_{i1}\, a_{i1},\ A_{i2}\, a_{i2},\ \ldots,\ A_{iK}\, a_{iK}],$$

where A_ik is the fading coefficient of traffic channel k, a_ik is the Mx1 spatial signature vector of traffic channel k, and K is the total number of OFDMA traffic channels (in frequency). When K=1, the above reduces to a narrowband setup. In contrast to the narrowband case where the spatial signature is "invariant" to the channel assignment, a broadband subscriber experiences different fading and spatial characteristics in different traffic channels.

A goal of broadband traffic channel assignment in OFDMA described herein is to allocate traffic channels to new subscribers (in the presence of on-going traffics) in a way that increases, and potentially maximizes, the system capacity. The process may be illustrated using Figure 3. Referring to Figure 3, on-going traffic identified by solid blocks occupy certain numbers of OFDMA traffic channels (e.g., channels 1, 2, 3, and 6), some of which, e.g., traffic channel 1, are shared by more than one subscribers using spatial multiplexing. The unshaded blocks represent OFDMA channels that are unoccupied (i.e., not being used). The shaded block represents traffic that is to be allocated or assigned to one or more OFDMA channels.

In one embodiment, several factors may be considered in determining which set of traffic channels are to be assigned to a new subscriber: (a) the channel fading conditions of the new subscriber at all traffic channels, (b) the spatial signature vectors of the new subscriber across all traffic channels, (c) the spatial signature vectors of on-going traffic, and (d) the data rate of on-going traffic of subscribers that have already been in communication with the base-station.

In the communication system described herein, channel allocation logic performs "channel-aware" traffic channel allocation. In one embodiment, the channel allocation logic provides bandwidth on demand and efficient use of spectral resources (e.g., OFDMA traffic channels) and spatial resources (e.g., the physical location of subscribers as it pertains to spatial beamforming) and performs traffic channel assignment based on broadband spatial channel characteristics of a requesting subscriber and on-going subscribers. Thus, the channel allocation may reduce resource usage (e.g., reduce usage of OFDMA channels).

In responding to a link request from a new subscriber, or when the base-station has data to transmit to a standby subscriber, the logic first estimates the spatial signature of the corresponding subscriber over all, or a

predetermined portion of OFDMA traffic channels. In one embodiment, the estimated information, along with the spatial characteristics of on-going subscribers are used to determine the achievable rate of the accessing subscriber over each of the OFDMA channels (with the presence of on-going SDMA subscribers). In an alternative embodiment, the estimated information and the spatial characteristics associated with on-going traffic channels are used to determine the SINR of the accessing subscriber over each of the OFDMA channels. The spatial characteristics may be stored in a register or other type of storage location (e.g., a spatial signature register).

In one embodiment, traffic channels that have the highest achievable rates and will not affect the rates of on-going traffic are assigned to the accessing subscriber to satisfy the rate request of the accessing subscriber.

In an alternative embodiment, traffic channels without the highest achievable rates may be allocated to a new subscriber, while leaving the traffic channels with the highest achievable rates to be allocated in the future. Similarly, traffic channels that affect the rates of subscribers due to some level of interference with on-going traffic may be allocated in certain instances. For example, in one embodiment, such allocations may occur

because the achievable rate is so high that the degradation of on-going traffic is tolerable.

A base-station architecture that communicates with multiple subscribers in an OFDMA/SDMA fashion is also disclosed. In one embodiment, the base-station includes multiple receiving antennas, each of which is connected to a down-converter, an OFDM demodulator, a 2-D spatial signature estimator, an on-going traffic register and an on-going traffic spatial signature register, an OFDMA/SDMA traffic channel allocation logic, an OFDMA medium access controller, an OFDM modem, an OFDM broadband beamformer, multiple up-converters, and multiple transmission antennas, each connected to one of the upconverters.

Figure 5 is a block diagram of an antenna array base-station that communicates with multiple subscribers through OFDMA and spatial multiplexing. Referring to Figure 5, the base-station 500 comprises receiving antenna array 500, a set of down-converters 501 coupled to receiving antenna array 300, an OFDM demodulator 502, a broadband (2-D) spatial signature estimator 503, an on-going traffic register 504, an OFDMA/SDMA traffic channel allocation logic 505, an on-going traffic spatial signature register 506, an OFDMA medium access controller (MAC) 507, an OFDM

modem 510, a set of parallel narrowband beamformers 509, a set of up-converters 508 and a transmission antenna array 511.

Uplink signals, including the accessing signal from a requesting subscriber, are received by receiving antenna array 500 and down-converted to the base-band by down-converters 501. The base-band signal is demodulated by OFDM demodulator 502 and also processed by the 2-D spatial signature estimator 503 for estimation of the accessing subscriber's broadband spatial signature using, e.g., an FFT based spatial signature estimator or other well-known parametric spatial channel estimation algorithms. The estimated 2-D spatial signature, along with spatial signature of subscribers corresponding to on-going traffic stored in the on-going traffic spatial signature register 506 and on-going traffic information stored in the on-going traffic register 504, are fed to OFDMA/SDMA traffic channel allocation logic 505 to determine a traffic channel assignment for the accessing subscriber, and possibly partial or all of the on-going subscribers. The results are sent to OFDMA MAC 507 that controls the overall traffic.

Control signals from OFDMA MAC 507 and downlink data streams 520 are mixed and modulated by OFDM modulator 510 for downlink transmission. Spatial beamforming can be applied with a set of parallel

narrowband beamformers 509 using spatial information stored in the on-going traffic spatial signature register 506. Specifically, the beamforming coefficients used by beamformers- 509 are calculated based on each subscriber's spatial signature. The output of beamformers 509 are up-converted by the set of up-converters 508, and transmitted through transmission antenna array 511.

In order to find one traffic channel assignment for the requesting subscriber, the traffic channel allocation logic first ranks all traffic channels in the order of the so-called achievable rate for the subscriber. In one embodiment, the achievable rate of the requesting subscriber over a particular traffic channel is limited by the noise power, its channel fading coefficient, and the spatial signatures of all co-channels subscribers in this channel. Other factors include the actual signal processing/communication techniques employed to separate the co-channel subscribers. Once the signal processing/communication techniques (e.g., technology for multi-user beam forming to separate multiple users) are selected, the base-station calculates the achievable data rate for the accessing subscriber and ongoing subscriber(s) over each of the traffic channels as shown in Figure 4. Referring to Figure 4, traffic channels in which on-going traffic are affected

with the addition of accessing subscriber are shaded. In one embodiment, for the accessing subscriber, its most favorable traffic channels are those corresponding to the highest rates, e.g., traffic channels 5, 4, 3, ... However, adding a new subscriber to a traffic channel with on-going subscribers may affect the traffic rates of on-going subscribers. Accordingly, in one embodiment, only traffic channels in which on-going traffic rates will not be affected by the addition of the new subscribers are reused. Alternatively, traffic channels in which on-going traffic is affected by a predetermined small amount (e.g., a tolerable amount for the application) may be allocated. Other traffic channels are shaded and marked "unusable" (in this case, traffic channels 1, 5, K-1) to the new subscriber.

Figure 6 illustrates operations performed by one embodiment of the traffic channel allocation logic. Referring to Figure 6, inputs to the channel allocation logic include the 2-D spatial signature of the accessing subscriber, A_new,1 a_new,1, ..., A_new,K a_new,K; the requested data rate, R_new from storage (not shown); the data rates of on-going traffic in each of the traffic channels from on-going traffic storage 601; and the 2-D spatial signatures of on-going subscribers from storage 602.

In one embodiment, the logic starts a loop from traffic channel 1 to traffic channel K and calculates the achievable rate for the accessing subscriber over each of the traffic channels. The results, R_new,1, ..., R_new,K, are saved for further evaluation. In another embodiment, the logic calculates the SINRs in a manner well-known in the art for the requesting subscriber over each of the traffic channels.

In calculating the achievable rate or the SINR value, different spatial processing algorithms, e.g., single-user detection and multi-user detection, may be used. The achievable rate or the SINR value depends on the actual spatial processing algorithm used in practice.

Also calculated are the achievable rates of on-going subscribers at each of the traffic channels with on-going traffic for the case that the requesting subscriber is added to that traffic channel: R_i,k, k=1, ..., K. Similarly, in an alternative embodiment, the logic can calculate the SINR values of on-going subscriber at each of the traffic channels, for that case that the requesting subscriber is added to that traffic channel.

The logic then examines whether these updated achievable rates (or SINRs) are lower than the actual rates (or SINR) requirements of subscribers with on-going traffic (e.g., a minimum data rate requirement that must be

satisfied). Note the actual rate may be higher when extra resources are available of subscribers with on-going traffic. Traffic channels in which the requesting subscriber is added and, therefore, in which the new rates or SINRs drop below the on-going rates or SINR thresholds are labeled "unusable" for the requesting subscriber. The remaining traffic channels are ranked and assigned in a descending order of the achievable rates or SINR values for the requesting subscribers. The thresholds may be set to ensure a specific signal quality at a particular data rate.

The process stops when the total rates for the requesting subscriber exceed a pre-determined value for the requesting subscriber.

Other criteria, e.g., the mean-squared errors of the spatial multiplexing outputs, the packet error rate in the case of packet data, etc., can be used for channel allocations in place of, or in addition to, the achievable rate.

Other Quality of Service (QoS) requirements of the new subscriber or other subscribers with on-going traffic, e.g., the packet delay, the throughput, and bit-error-rate, can be used in place of, or together with, the achievable rate or the SINR value in channel allocation.

Whereas many alterations and modifications of the present invention will no doubt become apparent to a person of ordinary skill in the art after having read the foregoing description, it is to be understood that any particular embodiment shown and described by way of illustration is in no way intended to be considered limiting. Therefore, references to details of various embodiments are not intended to limit the scope of the claims which in themselves recite only those features regarded as essential to the invention.

CLAIMS

We claim:

1. A network comprising:

a plurality of subscriber units to communicate with the base station using an orthogonal frequency-division multiple-access (OFDMA) protocol; and

a base station including

a memory to store broadband spatial signature vectors associated with each subscriber, the vectors being a function of frequency; and

traffic channel allocation logic to allocate OFDMA channels using the broadband spatial signature vectors of the subscribers.

2. The network defined in Claim 1 wherein the broadband spatial signature vectors are indicative of fading and spatial characteristics of the subscribers.

3. The network defined in Claim 1 wherein at least one of the spatial signature vectors is indicative of channel fading conditions of a new subscriber at all OFDMA traffic channels.

4. The network defined in Claim 1 further comprising data rate storage for storing information indicative of the data rate of on-going traffic.

5. A method comprising:

determining frequency and spatial characteristics of a plurality of orthogonal frequency division multiple access (OFDMA) channels for a new subscriber and one or more subscribers with on-going traffic;

allocating a subscriber one or more OFDMA channels based on on-going traffic among the OFDMA channels.

6. The method defined in Claim a further comprising:

assigning OFDMA/space-division multiple-access(SDMA) traffic channels to multiple access subscribers based on broadband channel characteristics, wherein the broadband channel characteristics comprise space and frequency characteristics.

7. A method comprising:

estimating spatial and frequency characteristics of propagation channels using a FFT-based or parametric channel estimation algorithm between a base station and a new subscriber;

accommodating a rate request of the new subscriber by assigning OFDMA traffic channels that use a first amount of transmission power and cause a second amount of interference to co-channel subscribers.

8. The method defined in Claim 7 wherein estimating characteristics of propagation channels is performed using a FFT-based or parametric channel estimation algorithm.

9. The method defined in Claim 7 wherein the first amount comprises a minimum amount of transmission power as compared to other OFDMA channels not assigned to the new subscriber.

10. The method defined in Claim 7 wherein the second amount comprises the least amount of interference caused to co-channel subscribers in comparison to interference caused to one or more subscribers if using one

or more of the OFDMA traffic channels that are not assigned to the new subscriber

11. The method defined in Claim 7 wherein estimating spatial and frequency characteristics comprise estimating a spatial signature of the new subscriber over a predetermined number of OFDMA channels.

12. The method defined in Claim 11 wherein the predetermined number of OFDMA channels comprises all of the OFMA channels.

13. The method defined in Claim 7 further comprising determining an achievable rate of the new subscriber over each of the OFDMA channels with a presence of on-going subscribers.

14. The method defined in Claim 13 wherein determining the achievable rate is performed using spatial characteristics of on-going traffic and a spatial signature of the new subscriber over all of the OFDMA traffic channels.

15. The method defined in Claim 7 further comprising assigning, to the new subscriber, OFDMA traffic channels with the highest achievable rates and least effect on other subscribers with on-going traffic over some portion of the OFDMA channels.

16. A method of assigning orthogonal frequency-division multiple-access (OFDMA) traffic channels in conjunction with a space-division multiple access (SDMA) protocol comprising:

estimating broadband spatial and frequency channel characteristics of a requesting subscriber;

determining, for each of the OFDMA traffic channel, an achievable rate of the requesting subscriber over each of the OFDMA traffic channels;

calculating, for each of the OFDMA traffic channel, a new achievable rate of at least one other subscriber with on-going traffic on one or more of the OFDMA traffic channels if the at least one other subscriber is to share the one or more OFDMA traffic channels with the requesting subscriber;

determining candidate traffic channels; and

allocating candidate traffic channels to the requesting subscriber unit to satisfy the requested data rate.

17. The method defined in Claim 16 wherein determining the achievable rate of the requesting subscriber comprises using single-user detection or multi-user detection.

18. The method defined in Claim 16 wherein performing spatial multiplexing includes performing single-user beamforming and multi-user beamforming.

19. The method defined in Claim 16 wherein allocating candidate traffic channels comprises performing channel allocation based on reducing resource usage while satisfying the QoS requirements of the subscriber.

20. The method defined in Claim 19 wherein performing channel allocation is based on minimizing the resource usage.

21. A base station comprising:

a plurality of receiving antennas;

a plurality of down converters coupled to the plurality of receiving antennas;

a new accessing subscriber spatial signature register;

an on-going traffic spatial signature register; and

an OFDMA traffic channel allocator coupled to the new accessing subscriber spatial signature register and the on-going traffic spatial signature register.

22. The base station defined in Claim 21 wherein the channel allocation logic allocates OFDMA channels to a new subscriber based on information from the new subscriber spatial signature register and the on-going traffic spatial signature register.

23. The base station defined in Claim 21 wherein the channel allocator comprises

a first input for a two-dimensional (2-D) spatial signature of an accessing subscriber;

a second input for a requested data rate of the accessing subscriber;

a third input for data rates of on-going traffic in each of the plurality of OFDMA channels;

a fourth input for 2-D spatial signatures of on-going subscriber;

achievable rate calculation logic coupled to the first, second, third, and fourth inputs to calculate an achievable rate for the accessing subscriber over each of the OFDMA channels and calculates updated achievable rates of subscribers at each of the OFDMA channels with on-going traffic as if the accessing subscriber is added to said each of the OFDMA channels; and

channel selection logic coupled to the achievable rate calculation logic to select OFDMA channels, based on achievable rates, for use by the accessing subscriber to achieve the requested data rate.

24. The base station defined in Claim 23 wherein the channel selection logic does not allocate OFDMA channels in which calculated updated achievable rates are lower than actual rates of subscribers with on-going traffic.

25. The base station defined in Claim 21 wherein the channel allocator comprises

a first input for a two-dimensional (2-D) spatial signature of an accessing subscriber;

a second input for a requested data rate of the accessing subscriber;

a third input for data rates of on-going traffic in each of the plurality of OFDMA channels;

a fourth input for 2-D spatial signatures of on-going subscriber;

calculation logic coupled to the first, second, third, and fourth inputs to calculate signal-plus-interference to noise ratio (SINRs) for the accessing subscriber over each of the OFDMA channels and calculates updated SINRs of subscribers at each of the OFDMA channels with on-going traffic as if the accessing subscriber is added to said each of the OFDMA channels; and

channel selection logic coupled to the calculation logic to select OFDMA channels, based on SINRs, for use by the accessing subscriber.

26. The base station defined in Claim 23 wherein the channel selection logic does not allocate OFDMA channels in which calculated updated SINRs are lower than actual SINRs of subscribers with on-going traffic.

27. The base station defined in Claim 21 further comprising:

an OFDMA medium access control (MAC) logic coupled to the channel allocator;

an OFDM modulator coupled to the OFDMA MAC logic;

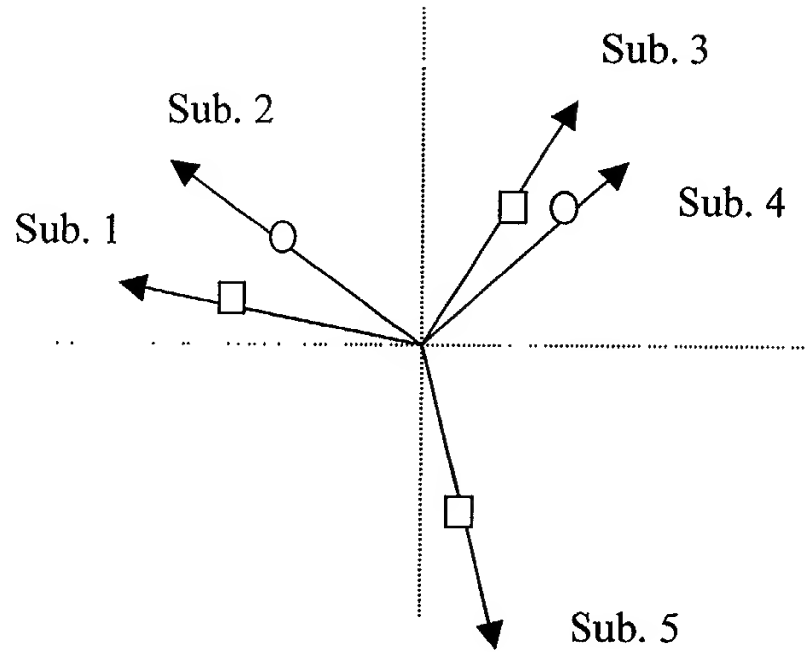
a plurality of parallel narrowband beamformers coupled to the OFDM modulation;

a plurality of upconverters coupled to the plurality of beamformers; and

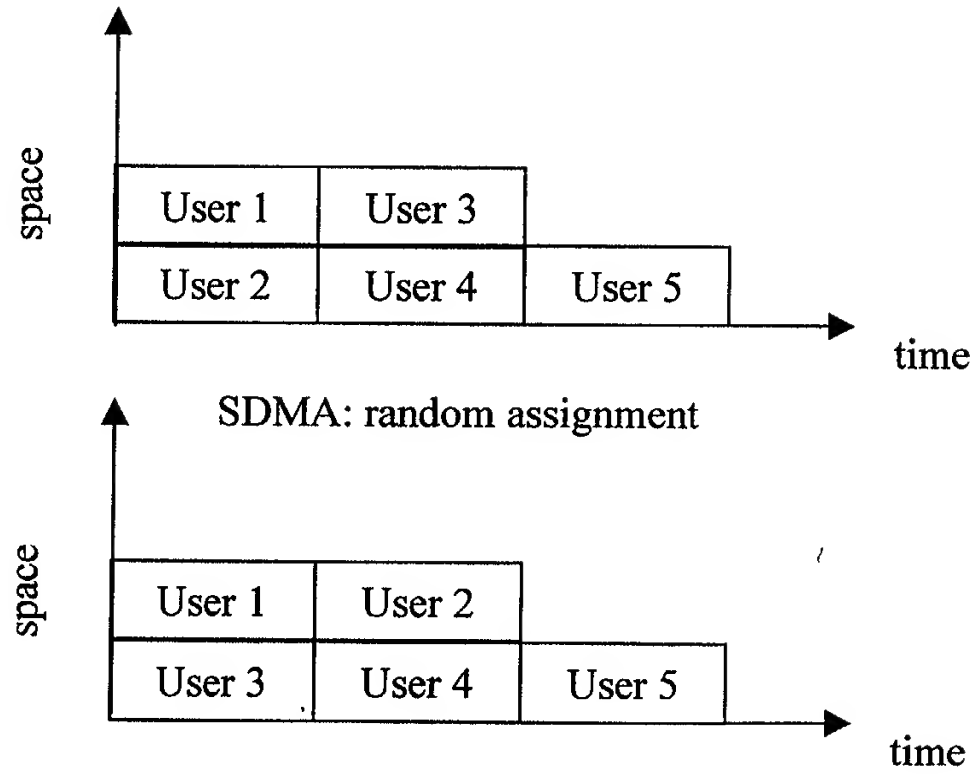
a plurality of transmitting antennas coupled to the plurality of upconverters.

ABSTRACT OF THE DISCLOSURE

A network is described. In one embodiment, the network comprises multiple subscriber units to communicate with the base station using an orthogonal frequency-division multiple-access (OFDMA) protocol, and a base station. The base-station includes a memory unit to store broadband spatial signature vectors associated with each subscriber and traffic channel allocation logic. The vectors are a function of frequency. The traffic channel allocation logic allocates OFDMA channels using the broadband spatial signature vectors of the subscribers.


Sub. 1
Sub. 2
Sub. 3
Sub. 4
Sub. 5

(A)


space
User 1
User 3
User 2
User 4
User 5
time
SDMA: random assignment
space
User 1
User 2
User 3
User 4
User 5
time
SDMA: channel-aware assignment

(B)

Figure 1

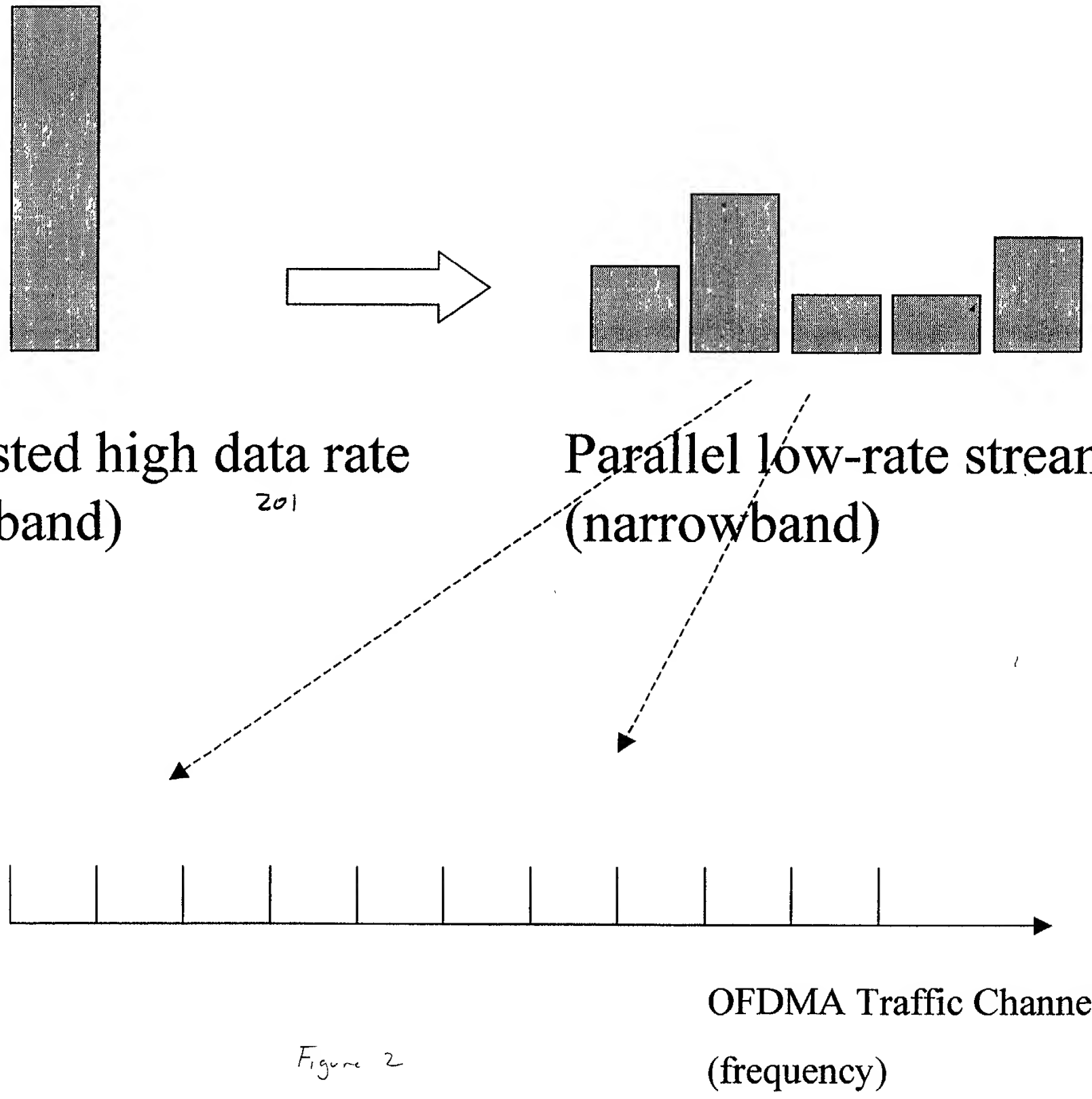
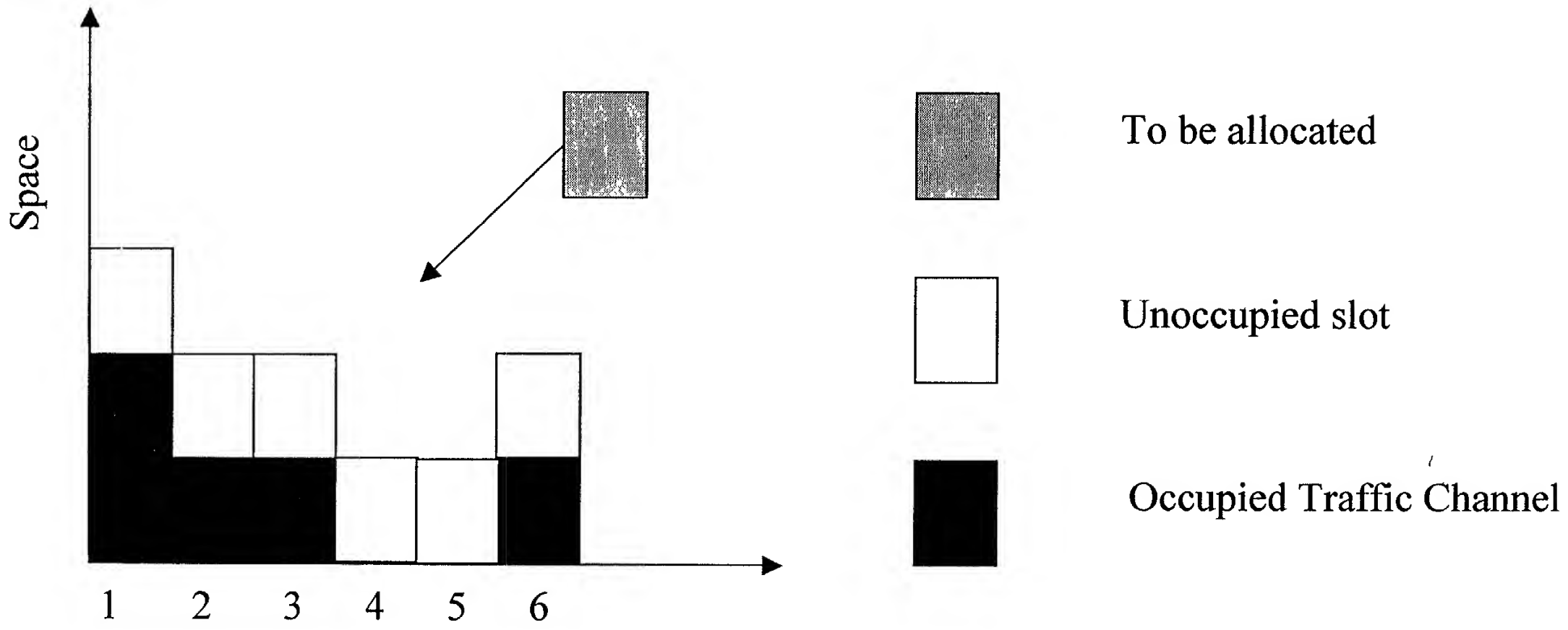

Requested high data rate
(broadband)
201
Parallel low-rate streams
(narrowband)
OFDMA Traffic Channels
(frequency)

Figure 2



OFDMA Traffic Channel

Figure 3

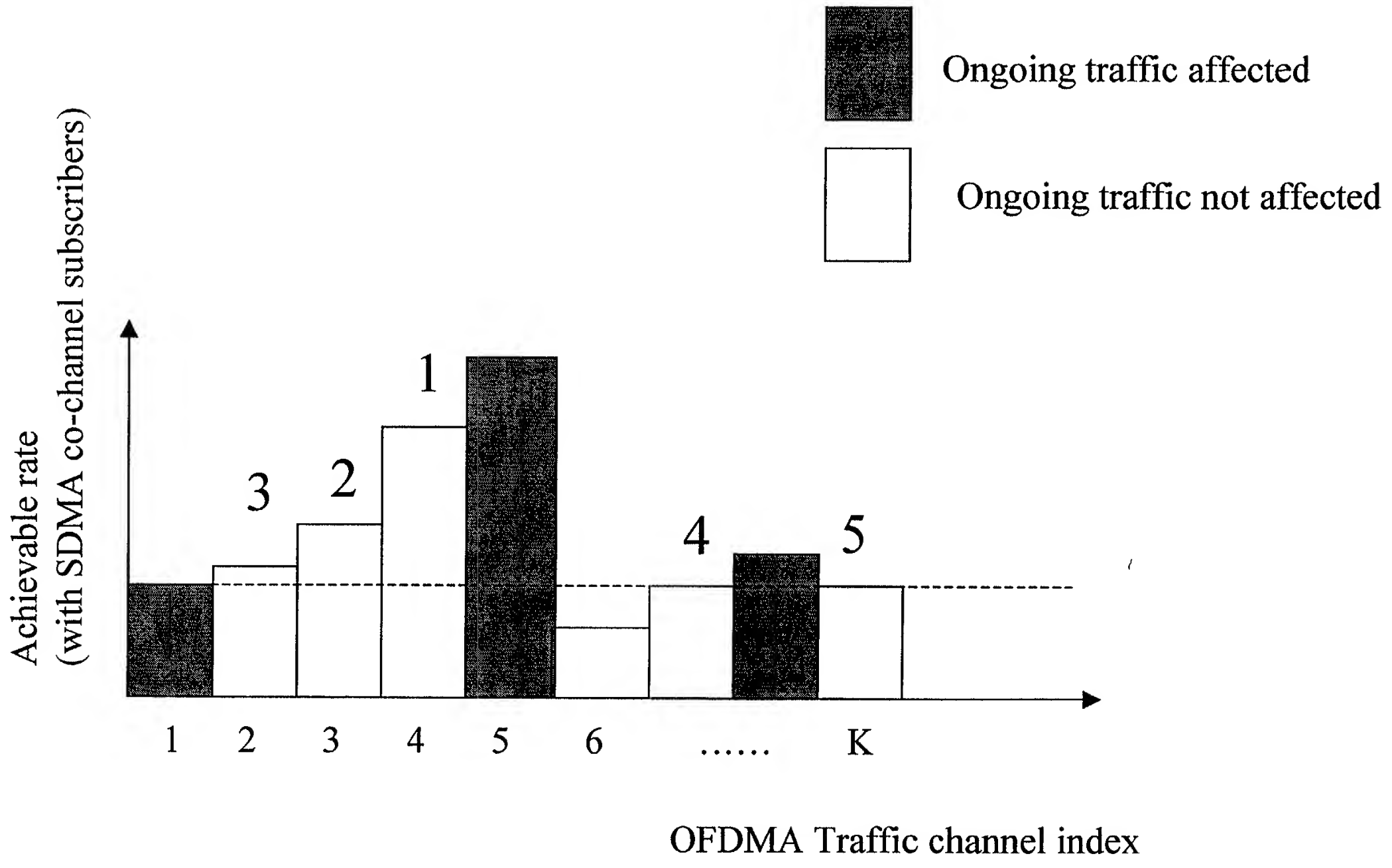

Ongoing traffic affected
Ongoing traffic not affected
Achievable rate
(with SDMA co-channel subscribers)
1
2
3
4
5
1 2 3 4 5 6 ..... K
OFDMA Traffic channel index

Figure 4

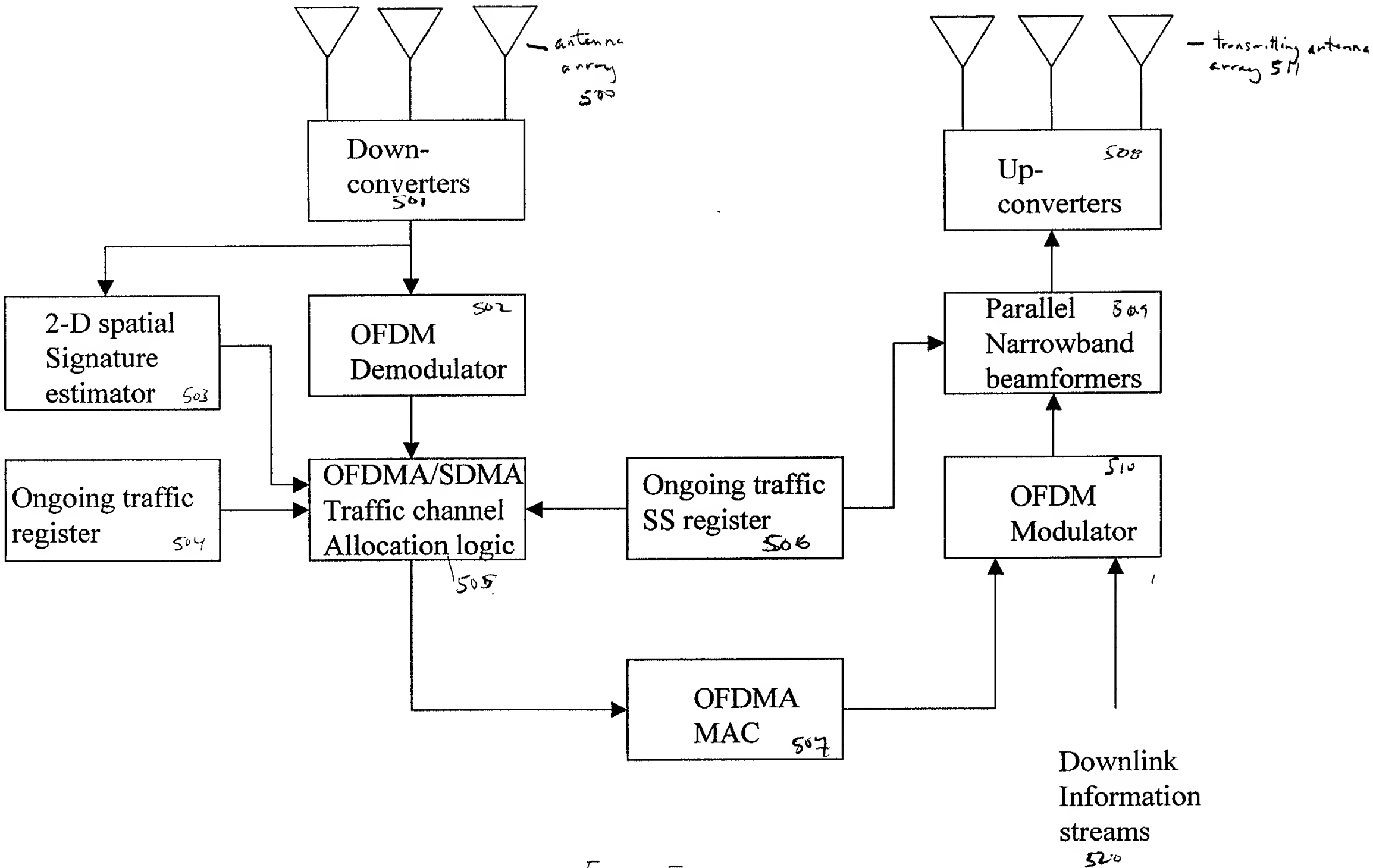

antenna array 500
Down-converters 501
2-D spatial Signature estimator 503
OFDM Demodulator 502
Ongoing traffic register 504
OFDMA/SDMA Traffic channel Allocation logic 505
Ongoing traffic SS register 506
OFDMA MAC 507
Up-converters 508
Parallel Narrowband beamformers 509
OFDM Modulator 510
transmitting antenna array 511
Downlink Information streams 520

Figure 5

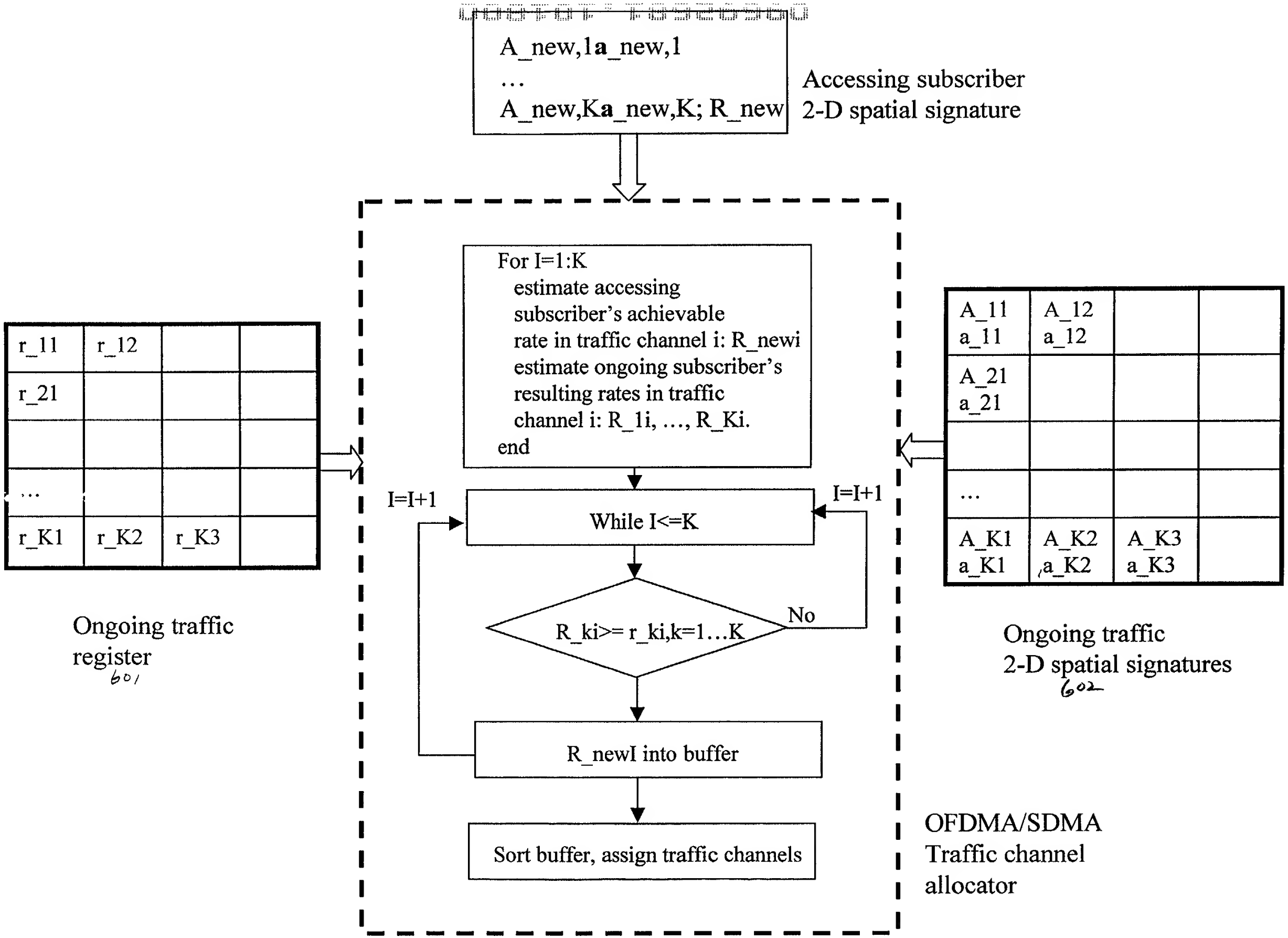

A_new,1a_new,1
…
A_new,Ka_new,K; R_new
Accessing subscriber
2-D spatial signature
For I=1:K
estimate accessing
subscriber's achievable
rate in traffic channel i: R_newi
estimate ongoing subscriber's
resulting rates in traffic
channel i: R_1i, …, R_Ki.
end
I=I+1
While I<=K
I=I+1
R_ki>= r_ki,k=1…K
No
R_newI into buffer
Sort buffer, assign traffic channels
r_11 r_12
r_21
…
r_K1 r_K2 r_K3
Ongoing traffic
register
601
A_11 a_11
A_12 a_12
A_21 a_21
…
A_K1 a_K1
A_K2 a_K2
A_K3 a_K3
Ongoing traffic
2-D spatial signatures
602
OFDMA/SDMA
Traffic channel
allocator

Figure 6

Attorney's Docket No.: 005158.P003 Patent

DECLARATION AND POWER OF ATTORNEY FOR PATENT APPLICATION

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below, next to my name.

I believe I am the original, first, and sole inventor (if only one name is listed below) or an original, first, and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled
CHANNEL ALLOCATION IN BROADBAND ORTHOGONAL FREQUENCY-DIVISION MULTIPLE-ACCESS/SPACE-DIVISION MULTIPLE-ACCESS NETWORKS

the specification of which

X is attached hereto.
___ was filed on (MM/DD/YYYY) _____ as
United States Application Number _____
or PCT International Application Number _____
and was amended on (MM/DD/YYYY) _____.
(if applicable)

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claim(s), as amended by any amendment referred to above. I do not know and do not believe that the claimed invention was ever known or used in the United States of America before my invention thereof, or patented or described in any printed publication in any country before my invention thereof or more than one year prior to this application, that the same was not in public use or on sale in the United States of America more than one year prior to this application, and that the invention has not been patented or made the subject of an inventor's certificate issued before the date of this application in any country foreign to the United States of America on an application filed by me or my legal representatives or assigns more than twelve months (for a utility patent application) or six months (for a design patent application) prior to this application.

I acknowledge the duty to disclose all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, Section 119(a)-(d), of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

Prior Foreign Application(s)			Priority Claimed
(Number)	(Country)	(Foreign Filing Date - MM/DD/YYYY)	Yes No
(Number)	(Country)	(Foreign Filing Date - MM/DD/YYYY)	Yes No
(Number)	(Country)	(Foreign Filing Date - MM/DD/YYYY)	Yes No

I hereby claim the benefit under title 35, United States Code, Section 119(e) of any United States provisional application(s) listed below:

(Application Number)	(Filing Date – MM/DD/YYYY)
(Application Number)	(Filing Date – MM/DD/YYYY)

I hereby claim the benefit under Title 35, United States Code, Section 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, Section 112, I acknowledge the duty to disclose all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application:

(Application Number)	(Filing Date – MM/DD/YYYY)	(Status -- patented, pending, abandoned)
(Application Number)	(Filing Date – MM/DD/YYYY)	(Status -- patented, pending, abandoned)

I hereby appoint the persons listed on Appendix A hereto (which is incorporated by reference and a part of this document) as my respective patent attorneys and patent agents, with full power of substitution and revocation, to prosecute this application and to transact all business in the Patent and Trademark Office connected herewith.

Send correspondence to Michael J. Mallie (Name of Attorney or Agent), BLAKELY, SOKOLOFF, TAYLOR & ZAFMAN LLP, 12400 Wilshire Boulevard 7th Floor, Los Angeles, California 90025 and direct telephone calls to Michael J. Mallie (Name of Attorney or Agent), (408) 720-8300.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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Inventor's Signature _____ Date _____

Residence _____ Citizenship _____
(City, State) (Country)

Post Office Address _____
_____

Full Name of Second/Joint Inventor Hujun Yin

Inventor's Signature _____ Date _____

Residence _____ Citizenship _____
(City, State) (Country)

Post Office Address _____
_____

Full Name of Third/Joint Inventor Li Xiaodong

Inventor's Signature _____ Date _____

Residence _____ Citizenship _____
(City, State) (Country)

Post Office Address _____
_____

Full Name of Fourth/Joint Inventor Fuqi Mu

Inventor's Signature _____ Date _____

Residence _____ Citizenship _____
(City, State) (Country)

Post Office Address _____
_____

APPENDIX A

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APPENDIX B

Title 37, Code of Federal Regulations, Section 1.56
Duty to Disclose Information Material to Patentability

(a) A patent by its very nature is affected with a public interest. The public interest is best served, and the most effective patent examination occurs when, at the time an application is being examined, the Office is aware of and evaluates the teachings of all information material to patentability. Each individual associated with the filing and prosecution of a patent application has a duty of candor and good faith in dealing with the Office, which includes a duty to disclose to the Office all information known to that individual to be material to patentability as defined in this section. The duty to disclosure information exists with respect to each pending claim until the claim is cancelled or withdrawn from consideration, or the application becomes abandoned. Information material to the patentability of a claim that is cancelled or withdrawn from consideration need not be submitted if the information is not material to the patentability of any claim remaining under consideration in the application. There is no duty to submit information which is not material to the patentability of any existing claim. The duty to disclosure all information known to be material to patentability is deemed to be satisfied if all information known to be material to patentability of any claim issued in a patent was cited by the Office or submitted to the Office in the manner prescribed by §§1.97(b)-(d) and 1.98. However, no patent will be granted on an application in connection with which fraud on the Office was practiced or attempted or the duty of disclosure was violated through bad faith or intentional misconduct. The Office encourages applicants to carefully examine:

(1) Prior art cited in search reports of a foreign patent office in a counterpart application, and

(2) The closest information over which individuals associated with the filing or prosecution of a patent application believe any pending claim patentably defines, to make sure that any material information contained therein is disclosed to the Office.

(b) Under this section, information is material to patentability when it is not cumulative to information already of record or being made or record in the application, and

(1) It establishes, by itself or in combination with other information, a prima facie case of unpatentability of a claim; or

(2) It refutes, or is inconsistent with, a position the applicant takes in:

(i) Opposing an argument of unpatentability relied on by the Office, or

(ii) Asserting an argument of patentability.

A prima facie case of unpatentability is established when the information compels a conclusion that a claim is unpatentable under the preponderance of evidence, burden-of-proof standard, giving each term in the claim its broadest reasonable construction consistent with the specification, and before any consideration is given to evidence which may be submitted in an attempt to establish a contrary conclusion of patentability.

(c) Individuals associated with the filing or prosecution of a patent application within the meaning of this section are:

(1) Each inventor named in the application;

(2) Each attorney or agent who prepares or prosecutes the application; and

(3) Every other person who is substantively involved in the preparation or prosecution of the application and who is associated with the inventor, with the assignee or with anyone to whom there is an obligation to assign the application.

(d) Individuals other than the attorney, agent or inventor may comply with this section by disclosing information to the attorney, agent, or inventor.